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In a two-component multiple variable interval schedule of reinforcement, responding in a blue, nonsignalled component was found to be a decreasing, negatively accelerated function of the rate of reinforcement in a red, signalled component. It was clearly demonstrated that the interaction between responding in one component of a multiple schedule and reinforcement rate in a second, regularly alternated component will occur in the absence of large variations in response rate in the component in which reinforcement rate is varied. Neither the Catania function for concurrent schedules nor the Lander and Irwin function for multiple schedules accurately predicted responding in the present situation, although a function of the same general form appeared appropriate.

When equal VI schedules were in effect in both components, the effect of signalling reinforcement in one component was a decrease in responding in the signalled component and a corresponding increase in responding in the unchanged component. Upon removal of the signal, responding in the previously signalled component recovered (increased), while responding in the unchanged component showed a gradual decline. Both positive and negative behavioral contrast were observed in the absence of changes in reinforcement rate.

The change from the signalled reinforcement condition to a free-reinforcement condition in one component produced no further increase in responding in the unchanged component. When reinforcement rate was increased in the free-reinforcement component, response rate in the unchanged component decreased. The effect of a reduction in responding accompanied by a simultaneous increase in reinforcement rate (mult VI 2 VI 2 -to- mult VI 2 VI 45"-signalled) was a decrease in responding in the unchanged component.

The interaction between responding in one component and reinforcement rate in a second component was well substantiated in the present series of experiments. However, any statement that responding in one component of a multiple schedule is "independent" of responding in a second component must be qualified by mention of those instances in which contrast effects have been observed in the absence of changes in reinforcement rate.

# THE EFFECTS OF SIGNALLED REINFORCEMENT IN MULTIPLE SCHEDULES OF REINFORCEMENT

by

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Approved by

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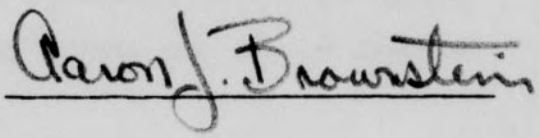
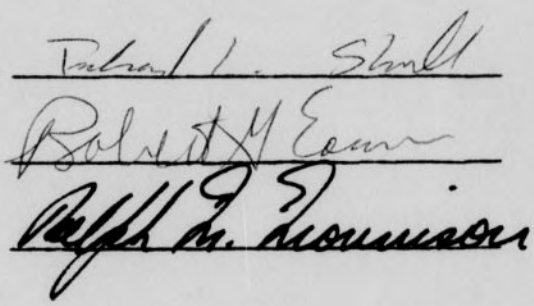
APPROVAL SHEET

This thesis has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

Thesis Adviser 

Oral Examination Committee Members 

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# CHAPTER I

## INTRODUCTION

A reinforcer has been defined by Morse (1966) as "any event which changes subsequent behavior when it follows behavior in time [p. 53]." Seldom are natural contingencies so arranged that every response emitted by an organism is followed by a reinforcer. It is more often the case that reinforcers are presented intermittently in time, the explicit contingencies being based on a combination of two factors. Either a response may be reinforced on the basis of the time which has elapsed since the preceding reinforcement (interval schedules of reinforcement) or on the basis of the number of responses which have been emitted since the last reinforcement (ratio schedules of reinforcement).

A schedule of reinforcement may be either fixed or may vary, either at random, or in some manner specified by the experimenter. These two possibilities yield the four basic schedules of reinforcement: fixed interval, variable interval, fixed ratio, and variable ratio (Ferster and Skinner, 1957). Many combinations of these basic schedules exist, two of which are multiple schedules and concurrent schedules.

A multiple schedule of reinforcement consists of two

or more alternating schedules of reinforcement with a different exteroceptive stimulus present during each. Schedules may simply alternate or alternate at random, with schedule changes usually being made after reinforcement. The organism reacts in a different way to two stimuli when they are appropriate to schedules having different effects (Ferster and Skinner, 1957).

Concurrent schedules of reinforcement are arranged in the following manner. Consider a pigeon pecking on two response keys. On each key, pecks are reinforced according to a particular schedule of reinforcement associated with that key. Each key is assigned its own schedule, so that availability of reinforcement on one key is not affected by the availability of reinforcement on the other key.

An alternative method is to assign both schedules of reinforcement to a single response key. Each schedule is paired with a particular exteroceptive stimulus, and only one or the other schedule is present at any given time. A second key is also present in the chamber, responding on which changes the exteroceptive stimulus of the main key and the schedule associated with it. This key is referred to as the changeover key, and the general procedure as the "changeover-key" procedure. In both procedures, each of the two schedules is continuously available. The only difference between the two concurrent procedures is in the changeover from one schedule to the other. In the two-key procedure,

the pigeon does this simply by moving from one key to the other, while in the changeover-key procedure, it must peck on the changeover key in order to change the stimulus conditions.

In both multiple and concurrent schedules, it has been shown that the rate of responding during the presentation of one of the stimuli may be altered by changing the schedule of reinforcement associated with the other stimulus. A change in the rate of responding in one component brought about by changing the schedule of reinforcement associated with the other component is called an interaction. In multiple schedules, a directly produced change in one component accompanied by an opposite change in responding in the unchanged component is termed behavioral contrast (Reynolds, 1961a). The interactions between component performances have been examined in detail in multiple schedules (Reynolds, 1961b, 1964, 1968). Analagous interactions between component performances in concurrent schedules have also been described (Herrnstein, 1961, 1964; Catania, 1963).

Catania (1966) has suggested that concurrent schedules may be considered, in form, as multiple schedules in which the control of the alternation from one schedule to the other is by the organism rather than by the experimenter. The changeover-key procedure, suggests Catania, separates the two components of the performance maintained by concurrent schedules into a multiple schedule of responding and

into changeover or choice responding. Thus, taken together, the multiple and choice components would appear to describe the concurrent performance completely. The extent, however, to which the separated component performances would match the corresponding concurrent performances has yet to be determined empirically.

Of particular empirical importance is the fact that with concurrent schedules of reinforcement the animal will match its relative rate of responding to the relative rate of reinforcement, as given by the expression:

$$\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2} \qquad (1)$$

where R and r identify the rate of responding and the rate of reinforcement, respectively, and the subscripts identify the components of the schedule. The time base for determining the response rate on each key is customarily taken to be the total session time, since both keys are available at all times.

Herrnstein (1961) and Catania (1963) have presented empirical evidence for the matching of relative response rate to relative reinforcement rate when the procedure incorporates the use of a changeover delay (COD). Without the COD, deviations from matching sometimes occur. The COD appears to be critical because it separates in time responses on one key and subsequent reinforced responses on the other key, and therefore prevents the schedule for one key

from obtaining accidental control over responding on the other key. Reynolds (1963) has shown that matching of relative number of responses and reinforcements does not occur in a multiple schedule of reinforcement.

Catania and Reynolds (1968) have demonstrated that in isolated variable interval schedules of reinforcement, the rate of responding can be expressed as a function of the obtained rate of reinforcement as given by the following equation:

$$R = Kr^{1/6} \tag{2}$$

where R and r identify the rate of responding and the rate of reinforcement, respectively, and where K is a constant.

For a concurrent situation, Catania then generalized equation (2) to the form:

$$(R_1 + R_2) = K(r_1 + r_2)^{1/6} \tag{3}$$

where R and r customarily identify the number of responses per minute and the number of reinforcements per hour, respectively, and where the subscripts identify the components of the schedule. The term K is a constant of proportionality. Equation (3) says that the overall rate of responding, when summed over both keys, is a function of the overall reinforcement rate summed over both keys, independent of the particular distribution of reinforcements and responses on the two keys.

On the basis of equations (1) and (3), Catania derived

and experimentally verified the following expression:

$$R_1 = \frac{Kr_1}{(r_1 + r_2)^{5/6}} \qquad (4)$$

Using a "changeover-key" concurrent procedure, Catania (1963, Exp. 1) showed that when responding on one key is reinforced according to a VI schedule, the response rate on that key is determined by the reinforcements per hour for that key and the reinforcements per hour for a second key, in the manner described by equation (4). Total output on two keys behaved like the total output on a single key. The ability of equation (4) to predict responding in one component, $R_1$, independently of responding in a second component, $R_2$, is witnessed by the absence of $R_2$ from the equation.

More direct support for the response independence assertion of equation (4) is given by Catania in a second experiment (Catania, 1963, Exp. 2). Again a "changeover-key" concurrent procedure was used. Two independent variable interval schedules were assigned, one to each of the two colors of the main key, with the illumination of the changeover key correlated with the schedule of key 1 (red). Between programmed reinforcements on key 1, the main key was yellow and the changeover key was dark. During this time, responding on the changeover key had no effect. When reinforcement was programmed on key 1 (red), the changeover key

was lit, and at this time a response on the changeover key would change the color of the main key from yellow to red. The changeover key remained lit until the reinforcement in the signalled component was delivered. The changeover key then went dark and the color of the main key changed back to yellow.

In a normal concurrent, the expected distribution of responses would be given by equation (1). Catania proceeded by varying the rate of reinforcement on the signalled key. However, with reinforcements in one component signalled, the pigeon pecked almost exclusively on the key that was not signalled, regardless of what the relative rates of reinforcement were. But although the animal spent more time in the unsignalled component, the rate of responding in the unsignalled component was found to vary inversely with the rate of reinforcement in the signalled component. It was found that the response rate on a single key, when reinforcements on the other key were signalled, was the same as when reinforcements on the other key were not signalled. Thus, rate of responding in one component of a concurrent schedule was found to be a function of the rate of reinforcement and independent of the rate of responding in the other component.

It could have been argued that even though the rate of responding on the unsignalled key did not depend on "measured" responding on the signalled key, it still may not

have depended exclusively on the rate of reinforcement on the two keys. Unmeasured responses were considered to have been orienting or observing responses that varied with the frequency of signals presented on the signalled key. If such responses were the case, they could have interfered with measured responding on the unsignalled key and contributed to the reduction in rate of responding as the frequency of signals on the signalled key increased. If so, it may not have just been the rate of reinforcement forcing the rate down on the other key, but the frequency of the signals.

In a subsequent experiment, Rachlin and Baum (1969) varied duration of reinforcement rather than rate of signalled reinforcement, thereby keeping constant throughout the rate of signalled reinforcement. If the latencies on the signalled key remained constant during the reduction of rate on the unsignalled key, then the reduction in response rate could be attributed to the direct influence of the duration of the signalled reinforcements, rather than to the frequency of the signals.

When duration of reinforcement (Rachlin and Baum) and rate of reinforcement (Catania) were both converted to seconds of access to reinforcement per unit time, the inverse relationship between responding on one key and reinforcement on the other key was obtained, thus confirming Catania's equation (4) and extending the equation to cover duration of reinforcement as well as rate of reinforcement.

The relatively constant latencies which were found further support the notion that responding on one key is directly influenced by reinforcement duration on the other key.

On the basis of the formal similarities between multiple and concurrent schedules of reinforcement and on the basis of the empirical relationships expressed in equations 1-4 (all having dealt with concurrent schedules), Lander and Irwin (1968) attempted to characterize the different effects of both multiple and concurrent schedules by values of a single parameter.

Three-minute components of red were alternated with three-minute components of green illumination of the response key. A session consisted of ten presentations of each stimulus condition. A variable interval schedule of reinforcement was associated with each stimulus condition. Although the matching relationship did not occur, there was a systematic relationship between total number of responses and the total number of reinforcements. Furthermore, this relationship could be described by an equation of the same form and exponent as equation (3).

Lander and Irwin have suggested that the distribution of reinforcements and responses in both multiple and concurrent schedules can be specified by the following expression:

$$\frac{R_1}{R_1 + R_2} = \frac{r_1^{\,a}}{r_1^{\,a} + r_2^{\,a}} \qquad (5)$$

where a = 1/3 is characteristic of multiple VI VI schedules and where a = 1 is characteristic of concurrent VI VI schedules.

By substitution of: $$R_1 + R_2 = K(r_1 + r_2)^{1/6}$$

We can write: $$R_1 = \frac{Kr_1^{\,a}(r_1 + r_2)^{1/6}}{r_1^{\,a} + r_2^{\,a}} \qquad (6)$$

The Lander and Irwin equation (6) states that the rate of responding, $R_1$, on one of the keys (for either a concurrent or a multiple schedule) is a joint function of the rate of reinforcement for that key, $r_1$, the rate of reinforcement for the other key, $r_2$, but is independent of the response rate on the other key, $R_2$. Direct support for the response independence function has already been described in detail for the case of concurrent schedules. However, direct support of a comparable nature for responding in multiple schedules is lacking at the present time.

A brief review and current statement of the problem is now in order. Catania (1963) established that the rate of responding in one component of a concurrent schedule of reinforcement could be expressed in terms of the rate of reinforcement in both components and independently of the rate of responding in a second component. Additional support for the response independence assertion in concurrent schedules was given by Rachlin and Baum (1969), who were

able to extend the equation of Catania to include responding as a function of the duration of reinforcement as well as of the rate of reinforcement. On the basis of the formal similarities and empirical relationships existing between multiple and concurrent schedules, Lander and Irwin (1968) suggested that the effects of both multiple and concurrent schedules could be characterized by values of a single parameter.

The present study is an investigation of the adequacy of the Lander and Irwin proposal to account for responding in one component of a two-component multiple schedule when the availability of reinforcement in a second component is "signalled." The purpose of the experiment somewhat parallels that of Catania (1963, Exp. 2). Both experiments, Catania with concurrent schedules and the present experiment with multiple schedules, represent efforts to assess directly the effects of reinforcement frequency on responding using procedures which effectively "suppress" responding in one component. The "signalling" procedure described below affords an opportunity to investigate response independence in multiple schedules as well as a means of evaluating the parametric values suggested by Lander and Irwin. In addition, the effective and immediate reduction in responding achieved by signalling reinforcements in one component of a multiple schedule provides critical data on the role of response suppression and reinforcement frequency in the generation of behavioral contrast.

# CHAPTER II

## METHOD

### Subjects

Seven adult male pigeons, designated P-1 through P-7, were used as subjects in the present experiment. Subjects P-1, P-2, and P-3 were Silver King pigeons approximately two years old at the beginning of the experiment. Subjects P-4, P-5, P-6, and P-7 were White Carneaux pigeons approximately one year old when the experiment was begun. All were obtained from the Palmetto Pigeon Plant and were housed in individual cages with continuous access to water. Lighting conditions consisted of a combination of artificial and natural illumination. No special lighting arrangement was maintained. Subjects P-1 through P-3 all had previous experience on variable interval schedules of reinforcement. Subjects P-4 through P-7 were experimentally naive at the beginning of the experiment. All were maintained at approximately 80% of their free-feeding body weights and given daily experimental sessions.

### Apparatus

The experimental chamber consisted of a converted picnic ice chest similar in design to that described by Ferster and Skinner (1957). Approximately 15 grams of force

was sufficient to operate a single translucent response key located four inches directly above a food hopper. The response key could be illuminated by either a red or a blue light. No house light was present. Each response produced an audible click from a feedback relay located behind the center partition. Reinforcement consisted of a 4½ second access to mixed grain. White noise was used to mask extraneous sounds. Standard relay programming equipment was employed.

Procedure

Initial training for subjects P-4 through P-7 was as follows. These subjects were auto-shaped to peck a key using the procedure described by Brown and Jenkins (1968). The next three experimental sessions each consisted of 60 reinforcements of key pecking on a continuous reinforcement schedule. Half of the reinforcements were obtained for pecking when the key was transilluminated with a red light, and half for pecking when the key was transilluminated with a blue light. Three sessions followed in which the red and blue illumination regularly alternated and responses in each illumination were reinforced on a variable interval 1-minute schedule of reinforcement. Each of the next 10 sessions consisted of ten 6-minute cycles of a two-component multiple schedule of reinforcement in which 3-minute components of red were followed by 3-minute components of blue illumination

of the key. In each illumination, a variable interval 2-minute schedule of reinforcement was in effect. The previous experimental histories of subjects P-1 through P-3 allowed them to be exposed directly to this condition (mult VI 2 VI 2).

When responding for all subjects showed day-to-day stability under the mult VI 2 VI 2 condition, ten sessions followed in which the illumination during the "red" component was present only when a reinforcement was made available by the tape programmer. During the remainder of the "red" component, the key was not illuminated, and the chamber was completely dark. Any key-pecks during these periods of blackout were recorded but were ineffective and produced no auditory feedback from the relay located behind the center partition. No change in illumination during the blue component was effected during these sessions. Hereafter, when reinforcements are programmed in this manner in the red component, this component is referred to as the "signalled" component. Following ten sessions in which reinforcements in the red component were "signalled" in this manner, ten sessions with the original red and blue illumination conditions were run; that is, the key was illuminated with red light throughout the red component and with blue light throughout the blue component.

All pigeons were then exposed to a series of multiple schedules, each consisting of two components: the first, a

variable component (red) in which reinforcements were "signalled," and the second, a constant component (blue) in which responding was always reinforced on a normal, non-signalled variable interval 2-minute schedule of reinforcement. Table 1 shows the variable interval schedules used in the red, signalled component throughout the experiment. Each schedule consisted of an arithmetic series of 13 intervals ranging from zero to twice the average value of the schedule and arranged in an irregular order.

The general procedure consisted of 10 daily sessions on a mult VI 2 VI 2-signalled condition, the mean response rate of the last five days in the blue component serving as a baseline for the following experimental condition. Experimental manipulations consisted of the systematic increase or decrease in the rate of reinforcement in the red signalled component (Table 1). Rate of responding in the blue, unchanged component was the primary observation throughout these manipulations. All experimental conditions were run for 10 daily sessions. Baseline performance on mult VI 2 VI 2-signalled preceded and followed each experimental condition.

An additional series of manipulations was performed to determine the effect on responding in the unchanged component when reinforcements in the other component were presented in a "free-reinforcement" condition. For three subjects (P-1, P-2, and P-3), following a determination of

TABLE 1

ORDER OF STIMULUS PRESENTATION
IN SIGNALLED COMPONENT

| P-1 | P-2 | P-3 |
|---|---|---|
| VI 2 | VI 2 | VI 2 |
| VI 2-S | VI 2-S | VI 2-S |
| VI 2 | VI 2 | VI 2 |
| VI 2-S | VI 2-S | VI 2-S |
| VI 6-S | VI 6-S | VI 45"-S |
| VI 2-S | VI 2-S | VI 2-S |
| VI 45"-S | VI 45"-S | VI 6-S |
| VI 2-S | VI 2-S | VI 2-S |
| TO | TO | TO |
| VI 2-S | VI 2-S | VI 2-S |
| VI 6-S | VI 45"-S | VI 45"-S |
| VI 2-S | VI 2-S | VI 2-S |
| VI 45"-S | VI 6-S | VI 6-S |
| VI 2-S | VI 2-S | VI 2-S |
| VI 1-S | VI 1-S | VI 1-S |
| VI 2-S | VI 2-S | VI 2-S |
| VI 4-S | VI 4-S | VI 4-S |
| VI 2-S | VI 2-S | VI 2-S |
| TO | TO | VI 2 |
| VI 2-S | VI 2-S | VI 2-S |
| VI 2-F | VI 2-F | VI 2-F |

TABLE 1 (continued)

ORDER OF STIMULUS PRESENTATION
IN SIGNALLED COMPONENT

| P-1 | P-2 | P-3 |
|---|---|---|
| VI 45"-F | VI 45"-F | VI 45"-F |
| VI 45"-S | VI 45"-S | VI 45"-S |
| VI 45"-F | VI 45"-F | VI 45"-F |
| VI 2 | VI 2 | VI 2 |
| VI 45"-S | VI 45"-S | VI 45"-S |
| VI 45 | VI 45 | VI 45 |

TABLE 1 (continued)

ORDER OF STIMULUS PRESENTATION
IN SIGNALLED COMPONENT

| P-4 | P-5 | P-6 | P-7 |
|---|---|---|---|
| VI 2 | VI 2 | VI 2 | VI 2 |
| VI 2-S | VI 2-S | VI 2-S | VI 2-S |
| VI 2 | VI 2 | VI 2 | VI 2 |
| VI 2-S | VI 2-S | VI 2-S | VI 2-S |
| VI 45"-S | VI 6-S | VI 6-S | VI 45"-S |
| VI 2-S | VI 2-S | VI 2-S | VI 2-S |
| VI 6-S | VI 45"-S | VI 45"-S | VI 6-S |
| VI 2-S | VI 2-S | VI 2-S | VI 2-S |
| TO | TO | TO | TO |
| VI 2-S | VI 2-S | VI 2-S | VI 2-S |
| VI 1-S | VI 1-S | VI 4-S | VI 1-S |
| VI 2-S | VI 2-S | VI 2-S | VI 2-S |
| VI 4-S | VI 4-S | VI 1-S | VI 4-S |
| VI 2-S | VI 2-S | VI 2-S | VI 2-S |
| VI 45"-S | VI 2 | VI 6-S | VI 1-S |
| VI 2 | VI 2-S | VI 2-S | VI 2-S |
| VI 45"-S | VI 2 | VI 2 | VI 2 |
| | VI 45"-S | VI 45"-S | VI 45"-S |
| | VI 45" | VI 45" | VI 45" |

baseline level on mult VI 2 VI 2-signalled, ten sessions followed in which reinforcements were presented in one component independent of responding. No illumination (neither house light nor key light) was present at any time during the 3-minute duration of the "free-reinforcement" component. No change in illumination occurred in the regularly alternated blue component. Any responses in the "free" component were recorded but were ineffective and produced no audible click from the feedback relay. In each component a variable interval 2-minute schedule of reinforcement was in effect. During the 10 sessions which followed, the rate of reinforcement in the "free" component was increased from VI 2-Free to VI 45"-Free.

The last series of manipulations to be performed sought to assess the effects on responding in the unchanged, blue component due to an increase in reinforcement rate in the alternated component, when this increase was accompanied by a simultaneous reduction in responding. Following responding on a mult VI 2 VI 2 schedule in which neither component was signalled, all seven birds were shifted to mult VI 2 VI 45"-signalled. After 10 days, the signal was removed and the key once again illuminated for the duration of the VI 45" component.

# CHAPTER III

## RESULTS

The results are presented in terms of three topics: (1) the effects of introducing the signalled reinforcement procedure, (2) terminal behaviors associated with varied signalled reinforcement rates, and (3) transitional behaviors following changes in signalled reinforcement rates. Several additional manipulations aimed at clarifying the role of response suppression and reinforcement frequency were also performed. The results of these additional manipulations will be presented last.

### Effects of Introducing the Signalled Reinforcement Procedure

The primary observation throughout the entire experiment was the rate of responding in the blue, nonsignalled component. The data for each bird was treated in the following way. The mean rate of responding in the blue component of the multiple schedule for the five sessions preceding the introduction of the signal was obtained. Rate of responding in the blue component during each of the 10 signalled sessions was normalized with respect to the mean rate of the five preceding nonsignalled sessions.

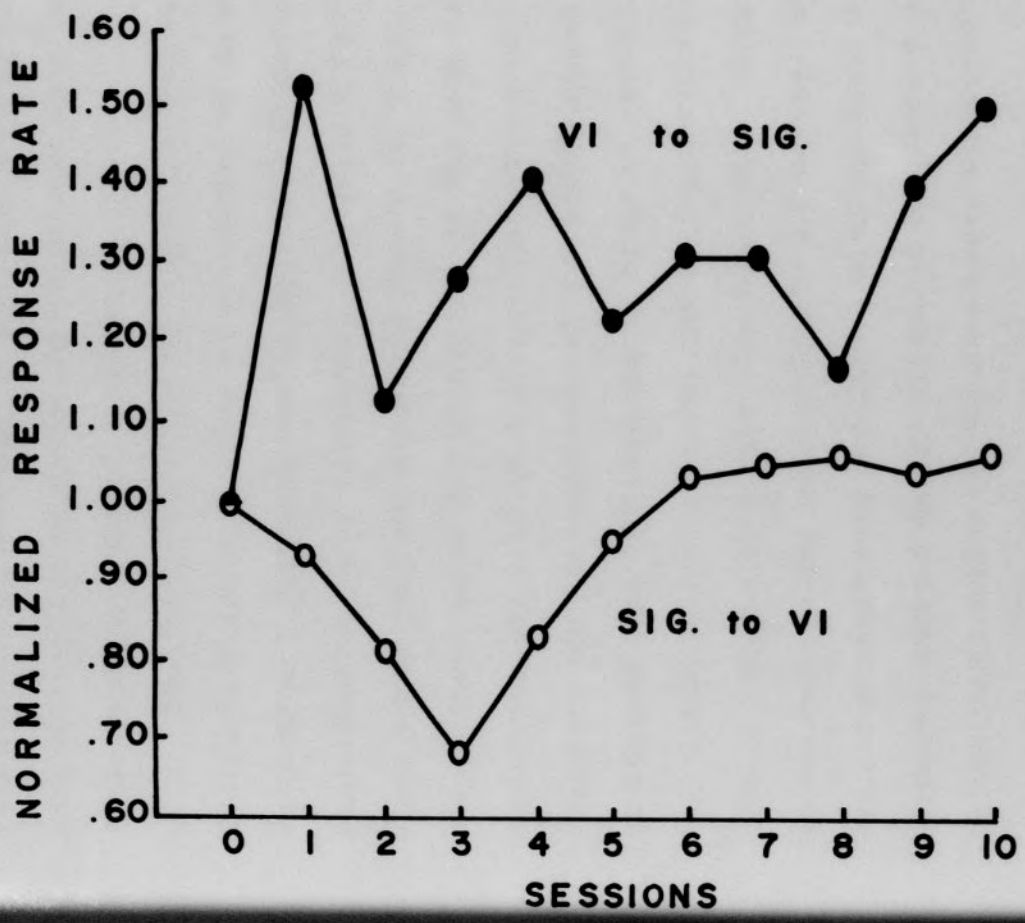
The introduction of the signalled reinforcement condition in one component of a mult VI 2 VI 2 schedule of

reinforcement produced an immediate reduction in responding in the component in which reinforcements were signalled. Responding in the unchanged component increased in the absence of any change in the rates of reinforcement. Obtained rates of reinforcement were equal in both components throughout the change from the nonsignalled to the signalled condition. When the signalling procedure was removed and the nonsignalled variable interval baseline reinstated, the rate of responding decreased in the component in which reinforcements had never been signalled.

The curve labeled VI to SIG. in Figure 1 presents the average rates for pigeons P-4, P-5, and P-6. All were experimentally naive at the outset of the experiment, having had only initial key-peck training. The mean rate of responding in the blue component preceding the introduction of the signal is represented as session 0. The relative rate of responding during the 10 signalled sessions which followed is clearly above 1.0, the value to be expected if the signalling procedure did not affect rate of responding in blue. This increase in rate of responding is representative of each of the three subjects mentioned above. Pigeon P-7, although having an identical experimental history to that of pigeons P-4, P-5, and P-6, showed no differential effect to the introduction of the signalled condition, its rate being very close to 1.0 throughout the series of operations performed. The group data are not greatly affected by

FIGURE 1

EFFECTS OF SIGNALLED REINFORCEMENT



the inclusion of the data from pigeon P-7, the only effect being to lower somewhat the average rates. Rates were still well above 1.0. Nothing in the prior history of this bird gave any indication as to why it did not show the effect of an increase in rate of responding.

The introduction of the signalled condition produced immediate changes in rates of responding which were apparent on session 1 following the introduction of the signal. The normalized rates of responding on session 1 for the three birds whose data are presented were 1.79, 1.47, and 1.32. All of these rates are within .16 of the peak rates observed during periods 1-10 of the signalled condition. The immediacy and the magnitude of the effect minimize the likelihood that the increase in rates of responding during the signalled condition was due to a general increase in the rate of responding in the blue component. Birds responded to the key (on the average within 1.8 seconds) whenever it was illuminated with red light, with the total number of responses emitted on the signalled key closely corresponding to the total number of reinforcements delivered in the signalled component.

The effect of removing the signal and reinstating the original multiple variable interval baseline schedule is shown in Figure 1 by the curve labeled SIG. to VI. Rates of responding in each of the 10 nonsignalled sessions were normalized with respect to the mean of the five preceding

signalled sessions. The data here are based on the mean rates of the same three birds mentioned above. A gradual decline in rate of responding in the blue component, which reached a maximum by the third day, followed removal of the signal. Recovery of responding in the red component was observed during the first session after the signal was removed, and was not correlated with the gradual decrease in responding which occurred in the blue component.

Corresponding changes in response rates were observed in only one of the pigeons with prior histories of responding on variable interval schedules. This was pigeon P-3. The data obtained from these animals with extensive prior histories were not felt to be representative of the effects of the independent variable and therefore have not been presented along with the data of the previously mentioned animals. Frequently, following long exposures to variable interval schedules, responding becomes characterized by an insensitivity to manipulations of the independent variable. The phenomenon is referred to as "locked rate" (Herrnstein, 1955). Only P-3 showed an increase in responding, whereas P-1 and P-2 were both insensitive to the introduction of the signalled reinforcement condition. The inclusion of these data has the effect of lowering the average rates. All, however, are still greater than 1.0. Their omission, therefore, was due to reasons of insensitivity rather than to any inconsistency. The decision was later supported by the

observation in pigeons P-1 and P-2 that their response rates were generally insensitive also to changes in the rate of signalled reinforcement. The only exception was for the VI 45"-signalled condition, the most extreme manipulation performed.

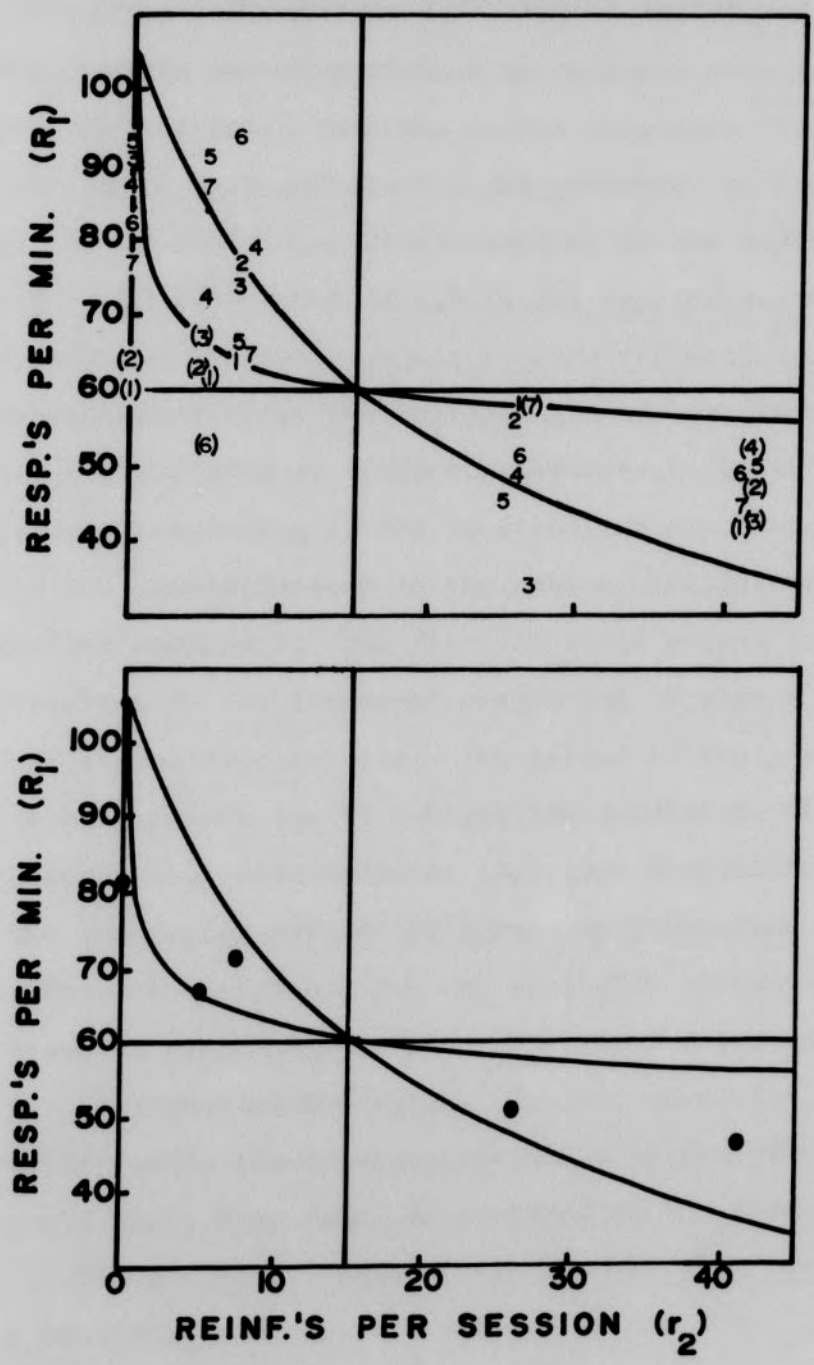
Terminal Behaviors Associated with Varied Signalled Reinforcement Rates

Changes in rate of reinforcement in the red, signalled component produced opposing changes in response rate in the blue, nonsignalled component. Again, rate of responding in the blue, nonsignalled component was the primary observation. Terminal schedule performance in the present experiment was defined as the mean rate of responding in the blue component for the last five days following a change in reinforcement rate in the red, signalled component.

The data were treated in the following manner. The mean response rate for the last five days under an experimental schedule was multiplied by whatever factor corrected the rate of responding under the preceding baseline to a value of 60 responses per minute, the value which approximated the average of all measures of baseline performance. The upper panel in Figure 2 shows the rate of responding in the nonsignalled component as a function of the number of obtained reinforcements in the signalled component. All points for a given subject are represented by the same

FIGURE 2

TERMINAL RESPONSE RATES



number. Circled points are the arithmetic mean of two corrected determinations.

If changes in reinforcement rate in the signalled component produce opposing changes in response rate in the nonsignalled component, then all points should be found to lie in the upper left and lower right quadrants of the figure. Of the 45 individual determinations in the upper panel of Figure 2, 43 were found to lie in the appropriate quadrants. Only two disparate points require explanation. Both of these represent first determinations, and both are generally classifiable as "induction effects." By this it is meant that responding in the nonsignalled component varied in the same direction as the rate of reinforcement in the signalled component. The first of these points requiring explanation is the increased responding of pigeon P-4 on the VI 45"-signalled condition. The second is the performance of pigeon P-6 on the VI 6-signalled condition. Following is a suggested explanation of these two disparities.

The unexpected periods of irregular responding which came to characterize pigeon P-4 may partially account for the increase in response rate under the first determination of the VI 45"-signalled condition. Inspection of the individual daily record showed that session 10 of the preceding baseline was 76.64 resp./min. as compared to the five day mean of 39.75 resp./min., suggesting somewhat that the effect may have been due to a general increase in the overall level

of responding. This notion would seem to be supported in light of the absence of any recovery when the baseline condition was reinstated. A second replication of the VI 45"-signalled condition after approximately 140 session produced responding appropriate to the schedule in effect; that is, the mean rate of responding was observed to decrease from 78.09 resp./min. to 26.17 resp./min.

The decrease in responding in the presence of the VI 6-signalled condition for pigeon P-6 is unexplained at this time. Equally unexplained is the recovery performance. The direction of responding in both instances is exactly opposite from expectation. A second replication of the VI 6-signalled condition for this bird produced essentially no effect. Responding under all other schedule conditions was appropriate.

The theoretical function of Lander and Irwin (1968) for multiple schedules and the function of Catania (1963) for concurrent schedules have been presented in Figure 2 for reference. Both functions, one for multiple schedules and the other for concurrent schedules, state that the rate of responding, $R_1$, on one of the keys is a joint function of the rate of reinforcement for that key, $r_1$, the rate of reinforcement for the other key, $r_2$, but is independent of the response rate on the other key, $R_2$. When $r_2$ is zero, both equations reduce to $R = Kr^{1/6}$, the formula for an isolated variable interval schedule. Therefore, the effect of

adding reinforcements in one component of a multiple VI VI schedule is to decrease responding in the other component below that observed in isolation. Furthermore, when rates of reinforcement are equal in both components, rates of responding are also equal. The value of K in both of these functions was determined by setting $R_1 = 60$, $r_1 = 15$, and $r_2 = 15$, and then solving for K. The value of K determined in this manner was 68.07. This value was selected so that both curves would pass through the same point as that representing performances under the baseline schedule.

The interactions which occur within each type of schedule are qualitatively similar. For example, an increase in the reinforcement rate in one component produces a decrease in the rate of responding in the other component. The interactions in concurrent schedules tend to be larger than analagous interactions in multiple schedules. The effects of these interactions in the present experiment can be seen in Figure 2. Both panels of Figure 2 depict rate of responding in the nonsignalled component, $R_1$, as a function of the number of reinforcements, $r_2$, obtained in the signalled component. The method for obtaining the points in the upper panel has already been described. The lower panel presents medians of the corrected response rates for each signalled reinforcement rate used in the experiment.

Inspection of Figure 2 reveals that neither function was able to accurately predict responding in the present

situation. However, the many procedural differences between the present study and the studies on which these functions were based suggest great caution in evaluating the appropriateness of either in the present signalled reinforcement situation. Although the particular parameter values chosen in these two functions were inadequate to accurately describe the present data, a function of the same general form would seem appropriate to describe these data.

If $r_1$ is held constant while $r_2$ is varied, both functions can be used to predict responding in the unchanged component, $R_1$. When these predicted points are then plotted on log-log coordinates, the points from both equations closely approximate straight lines. Neither equation plots exactly as a straight line, but the rate at which their respective slopes change over the values used in this experiment is so slight as to be difficult to detect. Since both functions so closely approximate straight lines when plotted in this manner, the predicted points from both functions were used to determine the best-fit lines given by an equation of the more general form: $\log Y = b \operatorname{Log} X + \log a$. The best-fit lines of this form for the data of individual subjects were also determined. Figure 3 presents the best-fit lines for individual subjects. Figure 3a presents the average of these individual functions in comparison with the functions of Lander and Irwin and Catania. The individual as well as group functions obtained in the present experiment

FIGURE 3

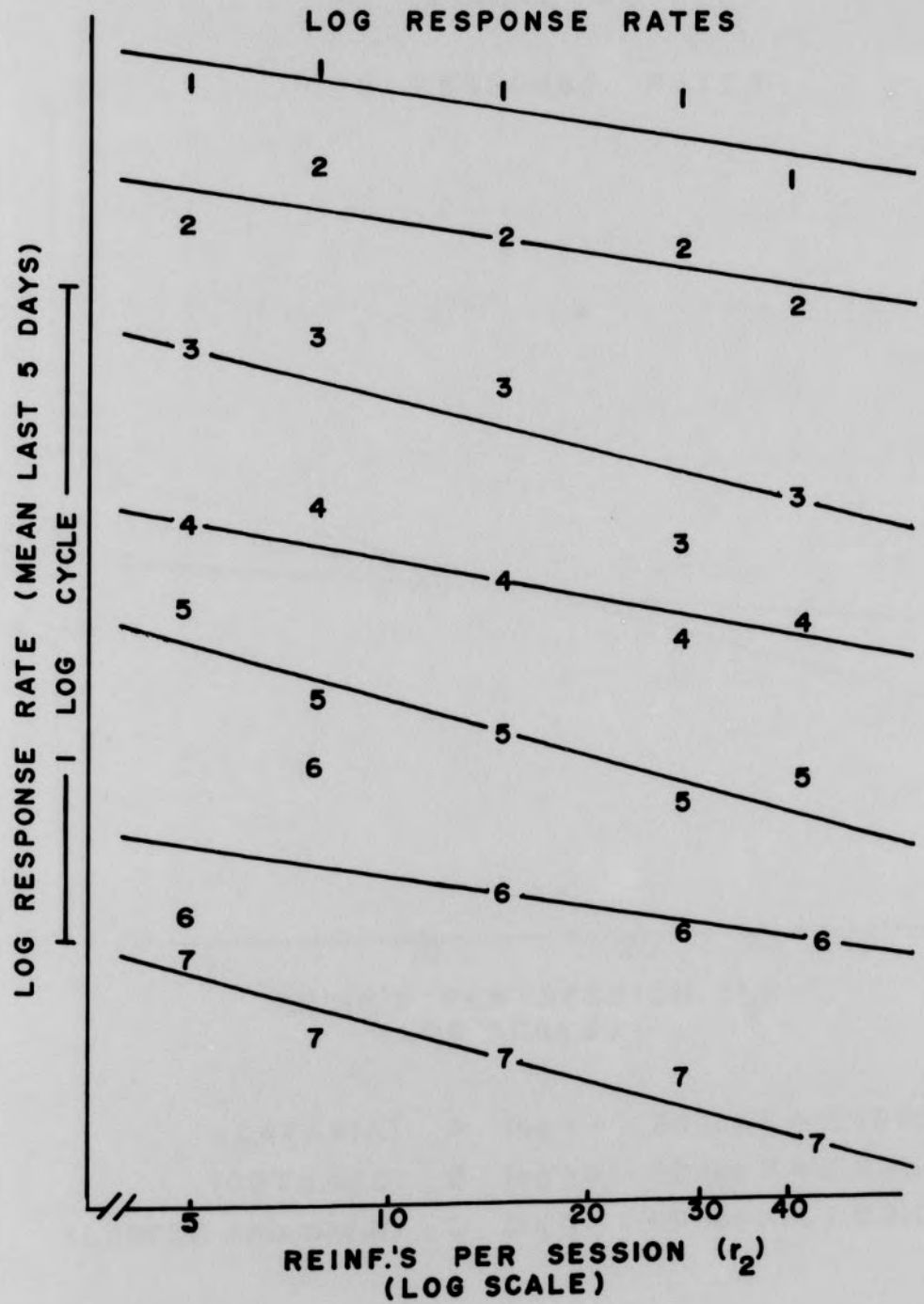
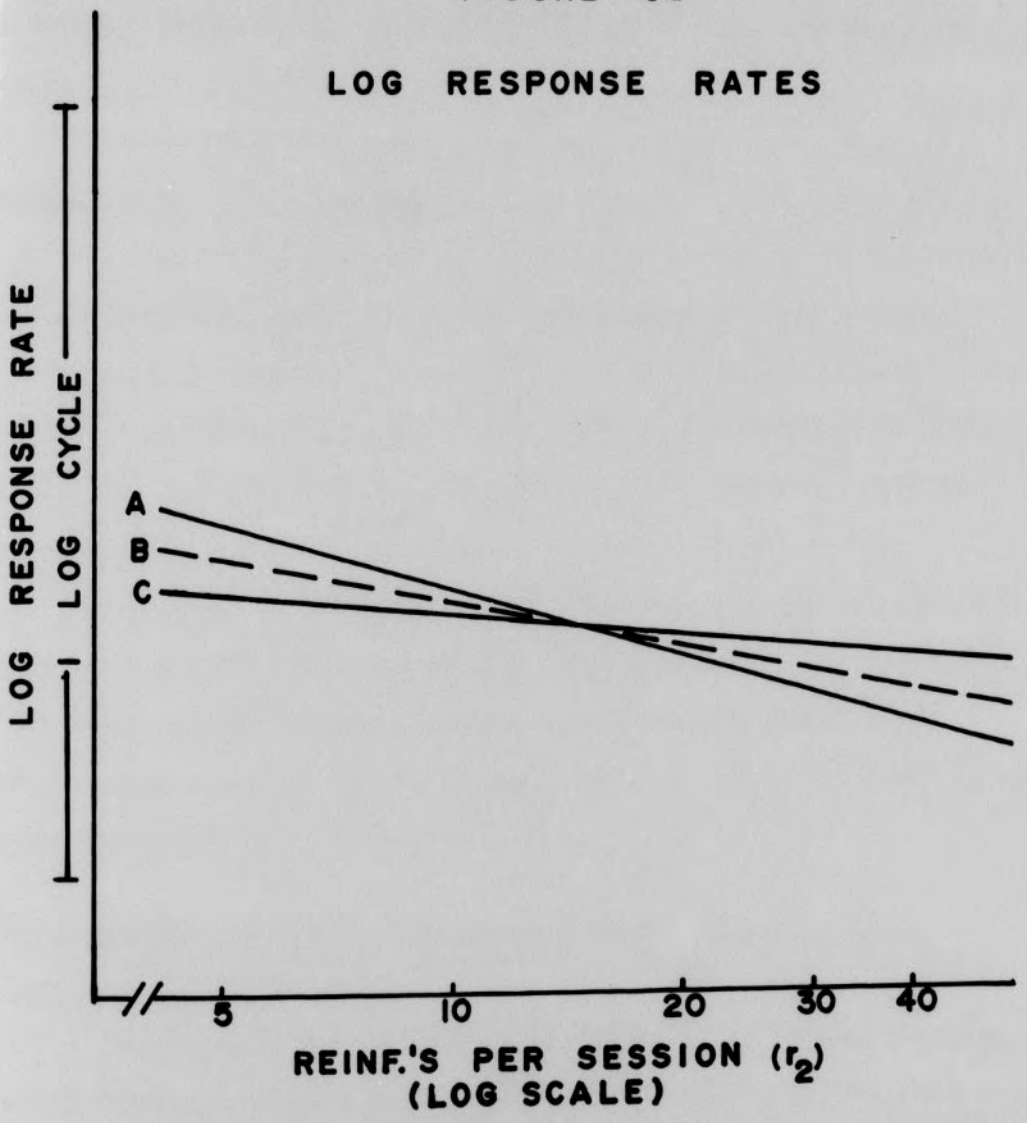

LOG RESPONSE RATES
LOG RESPONSE RATE (MEAN LAST 5 DAYS)
1 LOG CYCLE
1
2
3
4
5
6
7
5
10
20
30
40
REINF.'S PER SESSION ($r_2$)
(LOG SCALE)

FIGURE 3a




(CATANIA) A: $\log Y = -.36 \log X + 2.16957$

(OBTAINED) B: $\log Y = -.22 \log X + 2.02360$

(LANDER AND IRWIN) C: $\log Y = -.09 \log X + 1.88172$

where reinforcements were signalled are seen to be generally steeper than that predicted by the Lander and Irwin function, but less steep than is required by the Catania function.

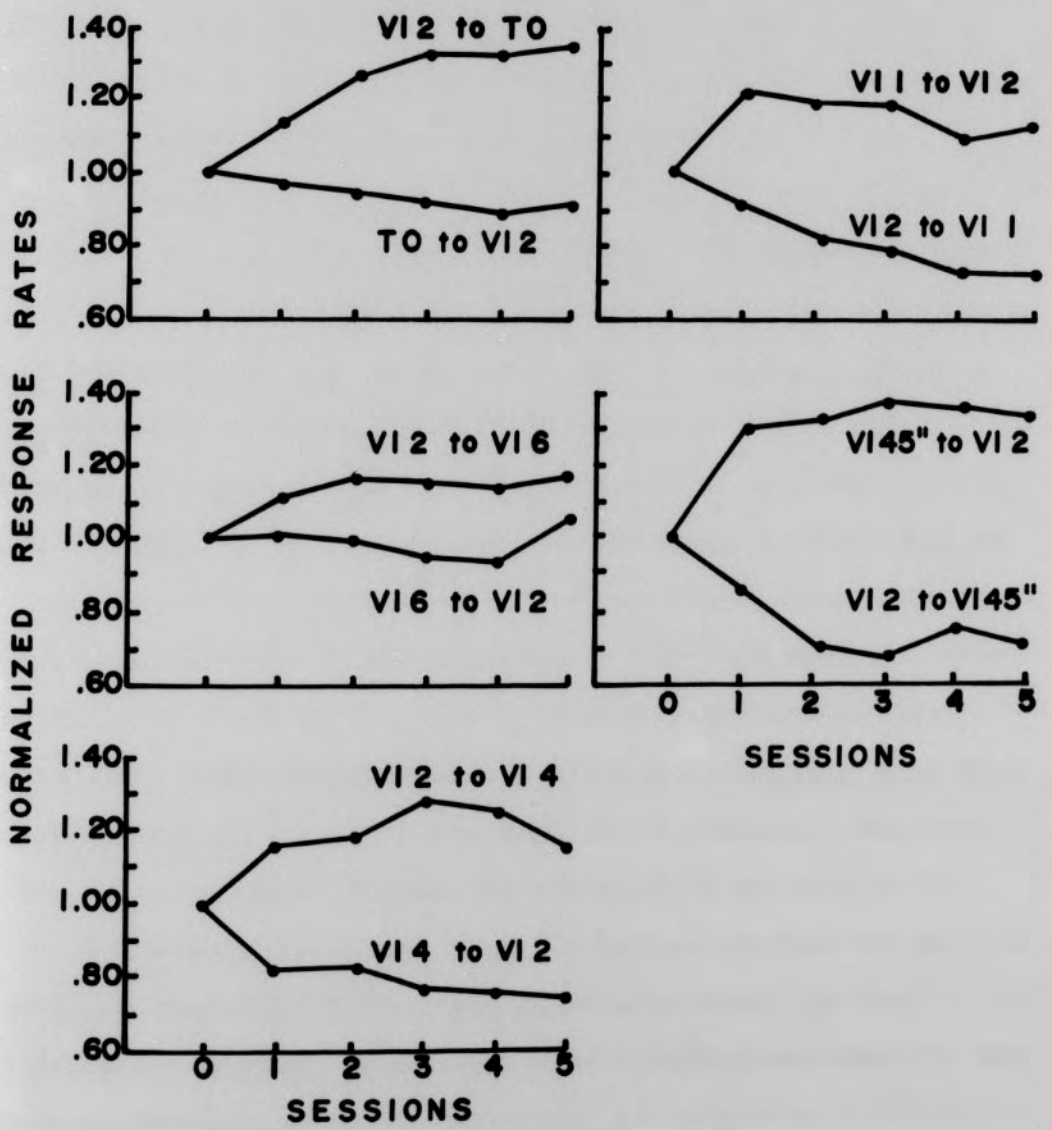
More important than the adequacy of these specific functions is that the suggested interaction between response rate in one component and reinforcement rate in another component was well substantiated. If response rate in the nonsignalled component was independent of reinforcement rate in the signalled component, the obtained points would fall along the line $R_1 = 60$. The major significance of the present data is that the distribution of obtained points is similar to that obtained when reinforcement rate is varied with nonsignalled VI procedures, and even more importantly, that this same interaction will occur in the absence of large variations in rate of responding in the component in which response rate is varied.

Transitional Behaviors Following Changes in Rate of Signalled Reinforcement

Figure 4 presents the normalized rates of responding in the blue unchanged component as a function of the five successive days following a change in reinforcement rate in the signalled component. The curves, which represent transitional responding, are based on data obtained from subjects P-3 through P-7. Transitional response rates are

FIGURE 4

NORMALIZED RESPONSE RATE ($R_1$)
FOLLOWING CHANGE IN SIG. REINF. RATE ($r_2$)



defined here as the daily rates of responding (expressed here as relative rates) for the first five sessions following a change in reinforcement rate. Because of the general insensitivity of subjects P-1 and P-2 to all but extreme manipulation in reinforcement rate, their data have not been included here. These data were in no way inconsistent. Their inclusion only serves to obscure somewhat the effects observed in the remainder of the subjects.

The data in Figure 4 were treated in the following manner. Rate of responding in the blue component for each of the first five signalled experimental sessions was normalized with respect to the mean response rate of the five preceding VI 2-signalled baseline sessions. The curves showing the recovery of the VI 2-signalled baseline following exposure to each experimental condition were treated in a similar manner, except that in this case, response rates have been normalized with respect to the mean response rate of the last five days of the preceding experimental condition. The normalized rates of individual subjects were then averaged across subjects for each daily session. The baseline value in these figures is represented as session 0.

The results showed that for those schedule values used, an increase in the rate of reinforcement in the signalled component produced a corresponding decrease in the rate of responding in the nonsignalled component. Likewise, a decrease in the rate of reinforcement in the signalled

component produced an increase in the rate of responding in the constant component. The effects obtained here with a signalled reinforcement procedure compare with those obtained with more usual contrast procedures. Any enhancement in rate of responding which may have been present throughout these manipulations due to the use of the signalled reinforcement procedure was partially taken into account by comparing all signalled experimental conditions to signalled baseline conditions.

The labeling of these behaviors as "transitional" and "terminal" is arbitrary and makes no assumptions as to the immediacy or duration of an effect, nor of the stability of responding following a change in reinforcement rate. Again, the important point to be made is that these interactions between response rate in one component and reinforcement rate in another component did occur, and that they did so in the absence of large variations in response rate in the component in which response rate was varied.

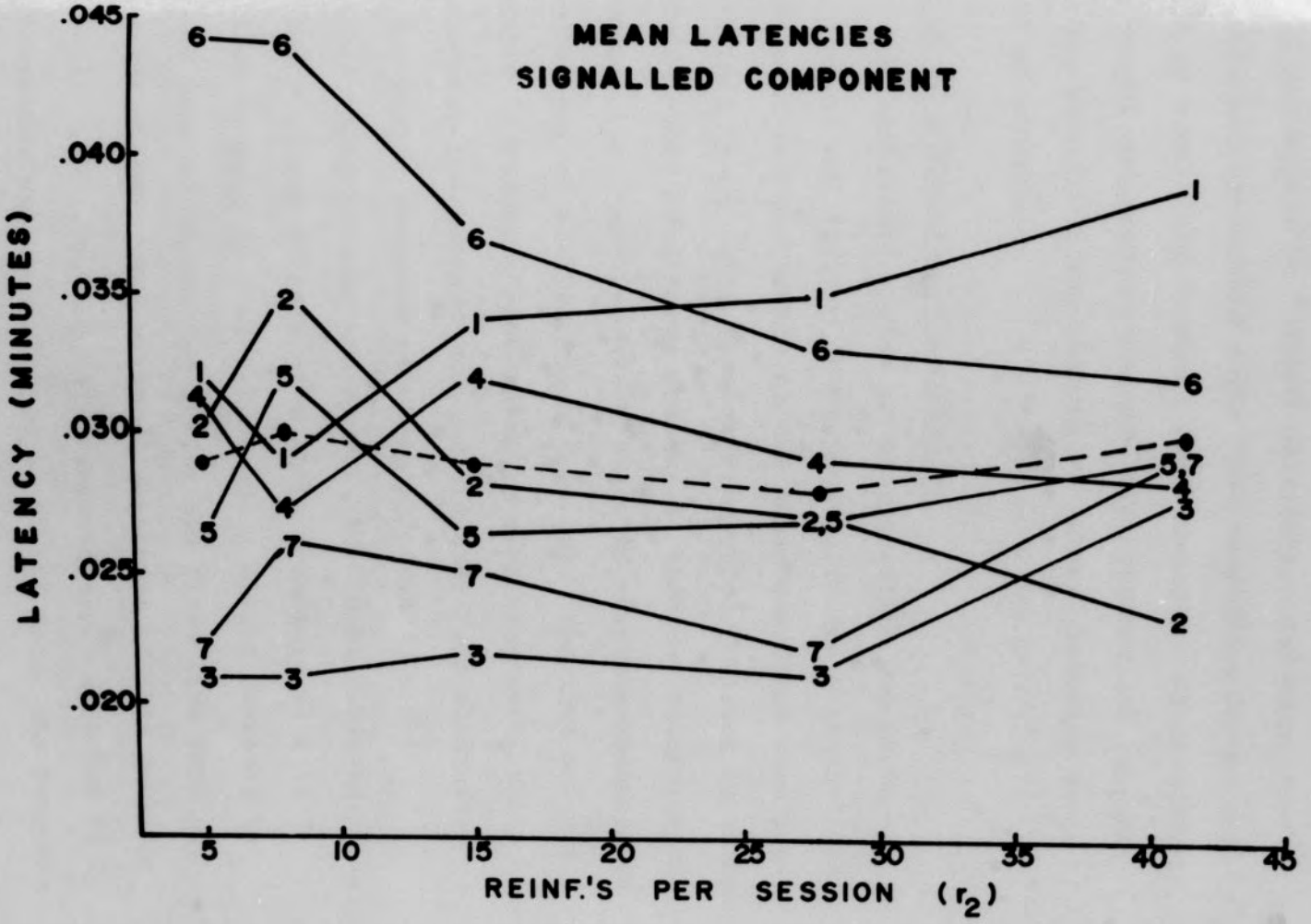
One source of concern is the possibility that these changes in response rates were being mediated by changes in body weight occurring over the course of a particular experimental session. Of particular concern are the changes in weight which occurred upon exposure to the VI 45"-signalled condition. For one subject, P-3, the increase in body weight following a change from VI 2-signalled to VI 45"-signalled (approximately 40 grams in excess of 80% level)

was maintained after the VI 2-signalled baseline was reinstated. This was accomplished by supplemental feeding in the home cage. Rate of responding was still observed to recover (increase). If body weight had been solely responsible for these changes in responding, the supplemental feeding should have resulted in either no change or a decrease in responding. For those experimental conditions where the reinforcement rate was decreased in the signalled component, supplemental feeding was carried out as a matter of procedure, and therefore is not of concern here.

Another possible concern is that changes in response rates in the unchanged component may have been due to the adventitious reinforcement of competing behaviors in the signalled component. Any behaviors engaged in during the periods of blackout could conceivably have come under schedule control, their frequency varying directly with the rate of signalled reinforcement. Therefore, as the rate of signalled reinforcement increased, the decreased response rate in the unchanged component could be attributed to the induction of these competing responses. The argument is somewhat analagous to that of observing responses in Catania's signalled concurrent procedure.

That such was actually the case is not likely for two reasons. First, although the behavior of the birds was not observed in the chamber during these blackouts, the relatively constant latencies shown in Figure 5 suggest that

FIGURE 5


MEAN LATENCIES
SIGNALLED COMPONENT
LATENCY (MINUTES)
.045
.040
.035
.030
.025
.020
5
10
15
20
25
30
35
40
45
REINF.'S PER SESSION ($r_2$)

during blackouts, animals remained oriented toward the key and did not engage in "other" behaviors. Secondly, Lander and Irwin had previously shown that responding in one component of a multiple schedule was independent of responding in a second component. Whether this hypothesized responding, therefore, was key-pecking or "other" behavior would not be of concern.

Results of Additional Manipulations

An additional series of manipulations was performed to determine the effects on responding in the unchanged component when reinforcements in the other component were presented in a "free-reinforcement" condition. Stated in terms of the stimulus conditions present in the free-reinforcement component, the conditions were those of response-independent presentations of food during a time out. The time out was effective in reducing responding to very near zero, while the response-independent presentations of food eliminated even the single response requirement present in the signalled reinforcement procedure. For three subjects, P-1, P-2, and P-3, the effects of a shift from mult VI 2 VI 2-signalled to mult VI 2 VI 2-Free was a slight decrease in the mean rate of responding during the first five days following the change. The relative magnitude of this decrease was small: .89, .96, and .93, respectively. When the VI 2-Free component was then changed to VI 45"-Free, the response

rate in the unchanged component decreased for subjects P-2 and P-3. The relative response rates in the unchanged component for the first five days following the change were .72 and .68. Pigeon P-1 showed no effect to the change, its relative rate remaining very close to 1.0.

A second series of manipulations was performed to determine the effects on responding in one component of a multiple schedule when an increase in reinforcement in a second component was accompanied by a simultaneous reduction in responding. It was shown at the beginning of the experiment that a reduction in responding in one component would produce an increase in responding in the unchanged component. However, it was also shown that an increase in rate of reinforcement in one component would produce a decrease in responding in an unchanged component. This manipulation involved a change from mult VI 2 VI 2 to mult VI 2 VI 45"-signalled. Figures 6 and 6a present the individual normalized rates of responding in the unchanged component of the multiple schedule when a second component was changed to VI 45"-signalled. Clearly, the effect was a decrease in the rate of responding. The effect of removing the signal at this point and reinstating the original continuous illumination in the red component was expected to result in a decrease in responding in the unchanged component. This manipulation, however, produced inconsistent changes in responding in the unchanged component.

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FIGURE 6

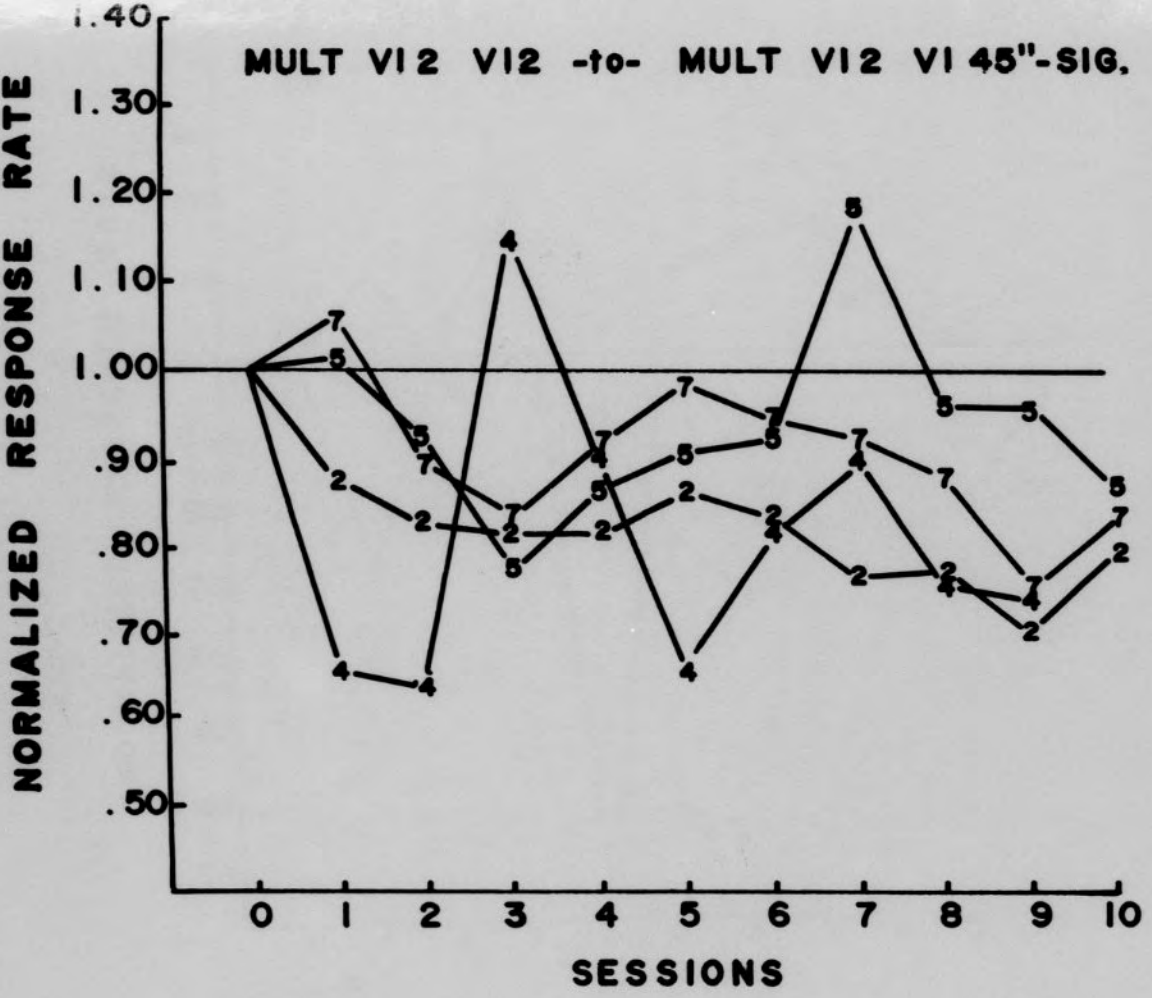
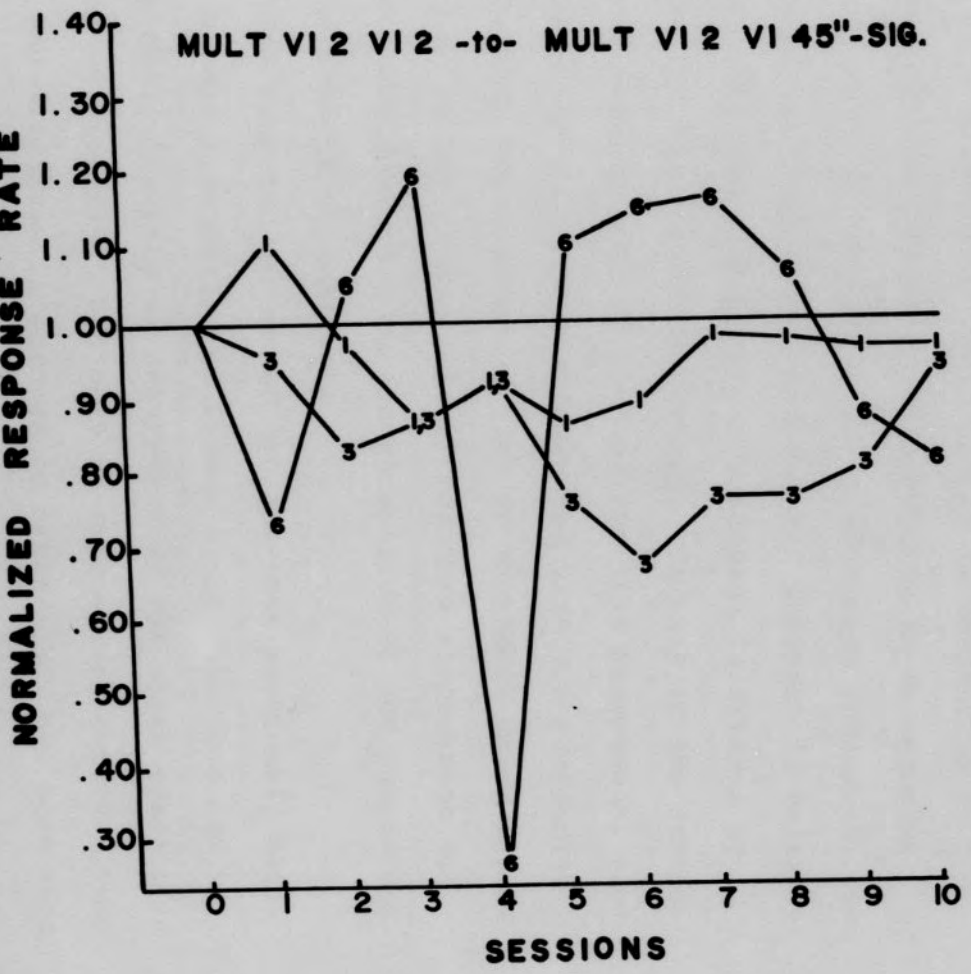

MULT VI 2 VI 2 -to- MULT VI 2 VI 45"-SIG.
NORMALIZED RESPONSE RATE
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
0 1 2 3 4 5 6 7 8 9 10
SESSIONS

FIGURE 6a


MULT VI 2 VI 2 -to- MULT VI 2 VI 45"-SIG.
NORMALIZED RESPONSE RATE
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
0 1 2 3 4 5 6 7 8 9 10
SESSIONS

# CHAPTER IV

## DISCUSSION

If a directly produced change in responding in one component of a multiple schedule results in an opposing change in rate of responding in an unchanged component, then behavioral contrast is said to occur. Contrast is reliably produced when responding in one component is altered by changing the rate of reinforcement. In many of the conventional procedures used to demonstrate this phenomenon, however, response rate and reinforcement rate are confounded. Consequently, there exists a lack of agreement among recent studies as to the proper role of response suppression and reinforcement frequency in the generation of the phenomenon known as behavioral contrast.

For example, if one of two operants previously maintained by equal schedules of intermittent reinforcement is extinguished, the rate of occurrence of the other operant is observed to increase. Not only is this effect observed when one of the schedules is changed to extinction, but also when the rate of reinforcement maintaining one of the operants is reduced. The demonstration of behavioral contrast using these conventional procedures does not allow one to independently assess the roles of response reduction and

reinforcement frequency, since in these procedures, the two variables covary.

Reynolds (1961a, 1961b) and others have proposed that contrast depends upon a relation among the schedules of reinforcement currently controlling an organism's behavior. This interpretation places the emphasis on relative reinforcement rates as a primary determinant of contrast. If the two components of a multiple schedule are of equal duration, the relative rate of reinforcement for a given component is given by the percentage of the total number of reinforcements obtained in that component. If the rate of reinforcement in one component is held constant, the relative rate of reinforcement in that component varies inversely with changes in the rate of reinforcement in the other component. If relative reinforcement rate is a determinant of contrast, then the effect should be produced when reinforcement rate in one component is varied.

One study which sought to separate the effects of these two variables, response reduction and reinforcement frequency, was performed by Bloomfield (1967). Arranging multiple schedules with a constant VI-1 minute schedule in one component, S1, and either a fixed ratio (FR) or a DRL schedule in the other component, S2, Bloomfield demonstrated that equivalent changes in the frequency of reinforcement in S2 resulted in similar effects on response rate in S1, regardless of whether the schedule in S2 led to high rates

of responding on FR or to low rates on DRL. These results were taken as support for a reinforcement interpretation of behavioral contrast.

Several recent studies have demonstrated, however, that positive behavioral contrast could be produced in multiple schedules where no increase in relative rate of reinforcement occurred in the component in which rate of responding was observed to increase.

Reynolds and Limpo (1968) reinforced key-pecking on a mult DRL DRL schedule of reinforcement in which a response exceeding an IRT of 35 seconds was reinforced. Following 16 sessions, an IRT clock (a series of visual stimuli correlated with the duration of each IRT) was added to one component. The results showed that positive behavioral contrast may occur during one component of a multiple schedule (normal DRL) even though the rate of reinforcement increases in the second component (DRL + IRT clock).

After establishing responding on a variable interval schedule of reinforcement, Terrace (1968) combined the variable interval schedule with a DRL schedule in a two-component multiple schedule. The values of the DRL were chosen so that the obtained rate of reinforcement in the DRL was equal to the obtained rate of reinforcement in the variable interval component. Terrace found that the rate of responding increased in the variable interval component relative to that observed in isolation. In a somewhat

similar manner, Weisman (1969) established responding on multiple VI VI schedules of reinforcement before changing one component to DRL, where the rate of reinforcement in the DRL was equal to that of the VI. Rate of responding in the VI component was observed to increase in the absence of any changes in relative rates of reinforcement.

In a fourth experiment, Brownstein and Newsom (1970) reduced responding in one component of multiple fixed interval schedules of reinforcement by an added cue light. Rate of responding in the noncued component was observed to increase when the rate of responding in the cued component was decreased by the addition of the cue. When the cue was removed, rate of responding decreased in the noncued component and increased in the component that had previously been cued. Both positive and negative behavioral contrast occurred in the absence of any change in the relative rates of reinforcement.

Lander (personal communication) has also produced positive contrast in multiple VI VI schedules. Following training on a mult VI VI schedule in which the rate of reinforcement in each VI component was 20 reinforcements per hour, one VI component was changed to a stimulus correlated VI (SCVI). Rates of reinforcement in both components were unchanged. Responding decreased in the component with the added stimulus and simultaneously increased in the unchanged component. Again, a reduction in responding in the absence

of any changes in reinforcement rates led to an increase in responding in the unchanged component.

These studies (Brownstein and Newsom, 1970; Lander, personal communication; Terrace, 1968; Weisman, 1969) have demonstrated that when reinforcement parameters are held constant in both components of a multiple schedule, a reduction in responding in one component is capable of producing an increase in responding in the unchanged component. It should be pointed out that the extent to which responding was reduced in these procedures differed, and that often subjects were exposed to periods of differential reinforcement before terminal behaviors were reached. The importance of these studies however is that they question the necessity of changes in reinforcement rates in the generation of behavioral contrast.

The signalled reinforcement procedure used in the present study sought to clarify the proper role of response suppression and reinforcement frequency in the generation of behavioral contrast. The reduction in responding achieved by signalling reinforcement in one component was both immediate and predictable. Birds were exposed to no periods of differential reinforcement during the changes from non-signalled to signalled reinforcement. Clearly, these data show that when reinforcement rates are held constant in both components of a multiple schedule, a reduction in responding in one component is a sufficient condition to produce an

increase in responding in the unaltered component. These data are consistent with the previously mentioned studies reporting an increase in responding in one component of a multiple schedule when responding is reduced in a second component.

The sufficiency of a reduction in responding in producing positive behavioral contrast in the above experiments is not questioned. However, as Morse (1966) has pointed out, "The demonstration that a variable is modifying behavior under certain circumstances is conclusive evidence that it 'can' operate under these conditions, but is only presumptive evidence that it 'will' modify behavior in other situations [p. 95]." Both a reduction in responding and a change in relative rates of reinforcement have been shown to be independently sufficient to produce contrast. The critical question, then, was what would be the effect on responding in an unchanged component produced by a reduction in responding and a simultaneous increase in reinforcement rate in a second component. Some evidence was already available on this from Reynolds and Limpo (1968). In their study, when responding decreased in the component with the added clock, reinforcement rate in that component increased. Responding in the component without the clock increased despite the fact that this increased responding resulted in a lowering of the reinforcement rate in that component.

In the present experiment, these conditions were

satisfied by first exposing subjects to mult VI 2 VI 2, and following the establishment of stable responding in this condition, by changing the schedule to mult VI 2 VI 45"-signalled. This represented a sizable increase in reinforcement rate (from 15 reinforcements per hour to 41 reinforcements per hour). At the same time, responding was reduced in this component to roughly 41 responses during the entire session. When these two variables, both shown to be sufficient in certain conditions, were allowed to vary in this manner, the observed effect was a reduction in responding in the unaltered component. This leads to the conclusion that where these two variables are free to vary in the same situation, reinforcement rate will be the variable that will come to control responding. Clear emphasis is given here to the importance of the schedules of reinforcement currently maintaining responding.

These observations were further extended by varying the rate of signalled reinforcement and observing its effect on responding in the unaltered component. The present data provide strong evidence for the interaction of reinforcement rate in one component with responding in a second component. Responding in the signalled component was reduced to within a range of from 15 responses per session on the VI 2-signalled condition to 41 responses per session on the VI 45"-condition. The decreasing, negatively accelerated function between responding in one component and reinforcement

rate in a second component was similar to that obtained with more conventional contrast procedures. As pointed out earlier, the present data clearly demonstrate that this interaction will occur in the absence of large variations in rate of responding in the component in which response rate is varied.

Data is now available which strongly support the inverse relationship between responding in one component of a multiple schedule and reinforcement rate in a second component. Although changes in responding in one component of a multiple schedule are predictable when reinforcement rate is varied in a second component, the occurrence of behavioral contrast in multiple schedules with equal reinforcement rates limits the generality of any statement of complete response independence in multiple schedules of reinforcement. In those studies in which reinforcement rates were held constant in both components, it was shown that a reduction in responding in one component was a sufficient condition to produce an increase in responding in an unchanged component. On the basis of available data, it now appears that neither of these two variables is both a necessary and sufficient condition for the production of behavioral contrast.

If a matrix such as that shown in Table 2 is constructed of all possible combinations which may occur in response rate in the unaltered component, $R_1$, when response rate, $R_2$, and reinforcement rate, $r_2$, are varied in a second

TABLE 2

MULTIPLE SCHEDULE INTERACTIONS

| Resp. Rate ($R_2$) | Reinf. Rate ($r_2$) | Resp. Rate ($R_1$) | |
|---|---|---|---|
| increase | increase | increase | generalization |
| increase | increase | decrease | negative contrast: Reynolds (1961a) EXT to VI; Brownstein, VI VIx to VI VI>x |
| increase | decrease | increase | Bloomfield (1967) FR |
| increase | decrease | decrease | VI limited hold (no data) |
| decrease | decrease | decrease | generalization |
| decrease | increase | increase | Reynolds & Limpo (1968) (DRL + IRT clock) |
| decrease | decrease | increase | positive contrast: Reynolds (1961a) VI to EXT; Brownstein, VI VIx to VI VI<x |
| decrease | increase | decrease | Brownstein & Hughes (unpub.) VI2VI2 to VI2VI45"-Sig. |
| increase | -------- | increase | response induction |
| increase | -------- | decrease | negative contrast: Brownstein & Hughes (1970). SIG. to VI |

TABLE 2 (continued)

MULTIPLE SCHEDULE INTERACTIONS

| Resp. Rate ($R_2$) | Reinf. Rate ($r_2$) | Resp. Rate ($R_1$) | |
|---|---|---|---|
| decrease | -------- | increase | positive contrast: Brownstein & Hughes (1970); Brownstein & Newsom (1970); Terrace (1968); Weisman (1969) Lander (personal communication); Brethower & Reynolds (1962) |
| decrease | -------- | decrease | response induction |
| -------- | decrease | decrease | Yarczower, et. al. (1966) mult (VI tan DRL) (VI tan DRL) |
| -------- | increase | decrease | Brownstein & Hughes (unpub.) VI2VI2-Free to VI2VI45"-Free |
| -------- | decrease | increase | VI2VI45"-Free to VI2VI2-Free (no data) |
| decrease | decrease | -------- | Ineffective Variables (no interaction) |
| decrease | increase | -------- | |
| increase | decrease | -------- | |
| increase | increase | -------- | |

component, the analysis is simplified to one of the possible interactions which may occur. Of particular interest in the analysis of behavioral contrast are those situations where opposing changes in response rates occur. It has been demonstrated that a decrease in responding in $R_2$ can produce an increase in responding in $R_1$, regardless of whether reinforcement rate, $r_2$, is increased (Reynolds and Limpo; mult VI 2 VI 2 to mult VI 2 VI 45"-signalled, present data) or decreased (Reynolds, VI to Ext.; Brownstein, varied VI rates). Where an increase in responding occurring in $R_2$ is accompanied by an increase in reinforcement rate, $r_2$, responding in $R_1$ is found to decrease (Reynolds, EXT to VI; Sig. to VI, present data). It is not known what effect an increase in response rate, $R_2$, accompanied by a decrease in reinforcement rate, $r_2$, would have on responding. No data is available on this at the present time.

Any analysis of behavioral contrast necessarily involves an investigation of the interactions occurring between responding and the schedules currently maintaining that responding. A thorough functional analysis of these interactions would seem preferable to a strict definitional account of the variables believed to be involved. A functional account of the variables in one component capable of producing changes in response rate in another component is essentially what is being proposed here.

The interactions which occur in both multiple and

concurrent schedules are qualitatively similar. General support for the formal assumptions of the Lander and Irwin function is given by these data, although procedural differences make any detailed comparison of responding difficult. The response independence function of Catania for concurrent schedules also provides a close approximation to the distribution of responses obtained in the present signalled reinforcement condition. Although responding in the present situation could not be accurately predicted by either function, the shape of the obtained function suggests that the use of a different value of the exponent a in the Lander and Irwin function could provide a function adequately describing the present data.

It should be pointed out that in the present study, when the VI 45"-signalled condition was in effect, the actual time spent in the signalled component was reduced from 30 minutes to 26.92 minutes (given a 4.5 second hopper time and 41 reinforcements). Therefore the response rate predicted for $R_1$ on the basis of the Lander and Irwin function is more correctly that for the condition where $r_2$ = 37 reinforcements per session. For the other reinforcement rates used, the actual times differ only slightly from 30 minutes. The effect, however, of this correction for the VI 45"-signalled condition is only to increase the slopes of the logarithmic functions in Figure 3 by +.01 each. The difference is slight, but in order to uphold the assumption of the function

with respect to equal component durations, the correction is preferable, although in this case not critical.

The rapidity with which these changes in response rate occur upon changes in reinforcement rate is specified by neither the Lander and Irwin function nor the Catania function. Transitional responding following changes in the rate of signalled reinforcement often showed sizable day-to-day variability. This day-to-day variability did not, however, obscure the clear effects of the interaction between reinforcement rate in one component and responding in the other component. The data are consistent with the observation that the magnitude of the interaction is generally proportional to the magnitude of the change in reinforcement rate. These differences in magnitude of responding are reflected in the rates of responding during the first five days following a change.

It has been suggested that further clarification of the topics discussed here might be achieved in a procedure in which reinforcements in one component of a multiple schedule were delivered in a "free-reinforcement" condition. The extent to which the signalled reinforcement procedure and a free procedure are comparable was examined. The further elimination of responding achieved in the free-reinforcement condition did not produce any further increase in responding. Most importantly, though, when rate of reinforcement in the free-reinforcement component was increased,

responding was found to decrease in the unaltered component. This clearly supports the assertion that responding in one component of a multiple schedule is a function of the rates of reinforcement in both components.

The signalled procedure was felt to be preferable to the free-reinforcement procedure on several procedural grounds. The single response requirement insured that the pigeon would be oriented toward the key at the time reinforcement was delivered, thus minimizing the possibility that the pigeon would be engaging in "other" behaviors (presumed to be behaviors other than key-pecking) at the time of reinforcement. It could, however, be argued that the onset of the key light acquired conditioned reinforcing properties and therefore became capable of maintaining the same types of presumed behaviors in the signalled component. However, responding on the signalled key was immediate and the relatively constant latencies which were found suggest that during blackouts, the pigeons remained oriented toward the key and did not engage in "other" behaviors. The procedure was, therefore, most similar to a normally programmed multiple schedule, in that responding was still reinforced in the presence of a discriminative stimulus, and reinforcement, although signalled, was still response-produced.

The extent to which the blackouts occurring between signalled reinforcements were possibly functioning as aversive stimuli could not be determined with the present

design. Such an interpretation, while plausible for accounting for an increase in response rate, would seem to be working against the observed effect when response rate was observed to decrease. The extent to which blackouts may possibly have been functioning as aversive stimuli and the extent to which they may have affected the reinforcement value of the schedule currently in force could be determined experimentally in a preference design using a concurrent chains procedure. Neuringer (1969) has reported similar data for the case of signalled versus nonsignalled FIs, but data on the present situation in VI schedules are not now available.

# CHAPTER V

## SUMMARY AND CONCLUSIONS

In a two-component multiple variable interval schedule of reinforcement, responding in one component is affected by changes in reinforcement rate in a second component. In the present experiment, three-minute components of red were alternated with three-minute components of blue illumination of the response key. Equal VI schedules of reinforcement were in effect in both components. When reinforcements were "signalled" in the red component, the key was illuminated with red light only when a reinforcement was made available by a tape programmer. During the remainder of the red component, the key was not illuminated. When responding was reduced in the red, signalled component in this manner, response rate in the blue, unchanged component increased. Upon removal of the signal, responding in the red component recovered to the presignal level, while responding in the blue component showed a gradual decline. Both positive and negative behavioral contrast were observed in the absence of changes in reinforcement rates.

Rate of signalled reinforcement was then varied in the red component while rate of reinforcement in the blue, nonsignalled component remained constant. Responding in the

blue, nonsignalled component was a decreasing, negatively accelerated function of the rate of reinforcement in the red, signalled component. These data clearly demonstrated that the interaction between responding in one component of a multiple schedule and reinforcement rate in a second, regularly alternated component will occur in the absence of large variations in response rate in the component in which reinforcement rate is varied. Comparison of the obtained data with the Catania function for concurrent schedules and with the Lander and Irwin function for multiple schedules showed that although neither accurately predicted responding in the present situation, a function of the same general form would seem able to adequately describe the data.

The further elimination of responding achieved by presenting reinforcements in one component independently of responding (free-reinforcement condition) produced no further increase in responding in the unchanged component. When reinforcement rate was increased in the free-reinforcement component, response rate in the unchanged component decreased. It was further demonstrated that in a situation where a reduction in responding was accompanied by a simultaneous increase in reinforcement rate (mult VI 2 VI 2 -to- mult VI 2 VI 45"-signalled), the effect was a decrease in responding in the unchanged component.

The interaction between responding in one component and reinforcement rate in a second component was well

substantiated in the present series of experiments. However, any statement that responding in one component of a multiple schedule is independent of responding in a second component must be qualified by mention of those instances in which contrast effects are observed in the absence of changes in reinforcement rate.

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# APPENDIX

## MEANS OF FIRST FIVE DAYS AND LAST FIVE DAYS: NONSIGNALLED COMPONENT

| | P-1 | | | P-2 | |
|---|---|---|---|---|---|
| | $\bar{X}_1$ | $\bar{X}_2$ | | $\bar{X}_1$ | $\bar{X}_2$ |
| VI 2 | ------ | 118.74 | VI 2 | ------ | 72.70 |
| VI 2-S | 112.31 | 102.13 | VI 2-S | 69.09 | 69.80 |
| VI 2 | 85.27 | 81.82 | VI 2 | 64.18 | 69.66 |
| VI 2-S | 97.56 | 80.38 | VI 2-S | 71.53 | 70.38 |
| VI 6-S | 92.31 | 88.47 | VI 6-S | 68.36 | 71.84 |
| VI 2-S | 97.95 | ------ | VI 2-S | 68.55 | ------ |
| VI 45"-S | 88.92 | 69.65 | VI 45"-S | 54.06 | 48.43 |
| VI 2-S | 72.07 | 79.43 | VI 2-S | 60.96 | 56.51 |
| TO | 73.31 | 83.57 | TO | 63.17 | 63.41 |
| VI 2-S | 112.95 | 92.11 | VI 2-S | 62.00 | 68.51 |
| VI 6-S | 87.64 | 89.91 | VI 45"-S | 56.90 | 57.83 |
| VI 2-S | 89.80 | 89.79 | VI 2-S | 62.47 | 66.72 |
| VI 45"-S | 78.33 | 63.01 | VI 6-S | 73.39 | 70.40 |
| VI 2-S | 74.75 | 71.45 | VI 2-S | 68.78 | 78.57 |
| VI 1-S | 68.51 | 68.78 | VI 1-S | 74.60 | 74.70 |
| VI 2-S | 67.60 | 80.09 | VI 2-S | 76.89 | 76.30 |
| VI 4-S | 78.19 | 85.95 | VI 4-S | 89.28 | 97.14 |
| VI 2-S | 79.39 | 92.56 | VI 2-S | 86.44 | 93.35 |
| TO | 94.36 | 87.40 | TO | 94.76 | 96.47 |

APPENDIX (continued)

MEANS OF FIRST FIVE DAYS AND LAST FIVE DAYS:
NONSIGNALLED COMPONENT

| | P-1 | | | P-2 | |
|---|---|---|---|---|---|
| | $\bar{X}_1$ | $\bar{X}_2$ | | $\bar{X}_1$ | $\bar{X}_2$ |
| VI 2-S | 77.77 | 79.52 | VI 2-S | 90.85 | 70.58 |
| VI 2-F | 71.14 | 73.07 | VI 2-F | 68.08 | 81.55 |
| VI 45"-F | 75.57 | 76.00 | VI 45"-F | 58.76 | 66.58 |
| VI 45"-S | 68.47 | 74.65 | VI 45"-S | 61.39 | 62.20 |
| VI 45"-F | 72.93 | ----- | VI 45"-F | 56.67 | ----- |
| VI 2 | 74.13 | 77.63 | VI 2 | 76.10 | 84.03 |
| VI 45"-S | 73.70 | 75.63 | VI 45"-S | 71.21 | 65.22 |
| VI 45" | 72.35 | ----- | VI 45" | 73.56 | ----- |

APPENDIX (continued)

MEANS OF FIRST FIVE DAYS AND LAST FIVE DAYS:
NONSIGNALLED COMPONENT

| | P-3 | |
|---|---|---|
| | $\bar{X}_1$ | $\bar{X}_2$ |
| VI 2 | ----- | 42.73 |
| VI 2-S | 57.91 | 54.90 |
| VI 2 | 39.72 | 43.93 |
| VI 2-S | 43.21 | 40.93 |
| VI 45"-S | 26.25 | ----- |
| VI 2-S | 37.48 | 37.61 |
| VI 6-S | 47.15 | 43.94 |
| VI 2-S | 37.81 | 39.05 |
| TO | 58.26 | 59.36 |
| VI 2-S | 55.22 | 43.44 |
| VI 45"-S | 28.25 | 33.85 |
| VI 2-S | 44.53 | 47.88 |
| VI 6-S | 52.04 | 50.92 |
| VI 2-S | 59.50 | 69.92 |
| VI 1-S | 48.77 | 39.01 |
| VI 2-S | 46.43 | 56.18 |
| VI 4-S | 67.67 | 67.23 |
| VI 2-S | 43.72 | 54.71 |
| VI 2 | 45.87 | 62.20 |

APPENDIX (continued)

MEANS OF FIRST FIVE DAYS AND LAST FIVE DAYS:
NONSIGNALLED COMPONENT

| | P-3 | |
|---|---|---|
| | $\bar{X}_1$ | $\bar{X}_2$ |
| VI 2-S | 68.98 | 54.76 |
| VI 2-F | 50.74 | 48.14 |
| VI 45"-F | 32.54 | 38.91 |
| VI 45"-S | 31.26 | 34.79 |
| VI 45"-F | 35.11 | ----- |
| VI 2 | 48.12 | 52.27 |
| VI 45"-S | 45.24 | 42.74 |
| VI 45" | 42.11 | ----- |

APPENDIX (continued)

MEANS OF FIRST FIVE DAYS AND LAST FIVE DAYS:
NONSIGNALLED COMPONENT

| | P-4 | | | P-5 | |
|---|---|---|---|---|---|
| | $\bar{X}_1$ | $\bar{X}_2$ | | $\bar{X}_1$ | $\bar{X}_2$ |
| VI 2 | ----- | 37.10 | VI 2 | ----- | 47.13 |
| VI 2-S | 49.54 | 57.87 | VI 2-S | 66.55 | 72.23 |
| VI 2 | 43.97 | 53.45 | VI 2 | 59.31 | 70.34 |
| VI 2-S | 67.54 | 39.75 | VI 2-S | 78.59 | 47.15 |
| VI 45"-S | 46.20 | 55.23 | VI 6-S | 61.41 | 71.51 |
| VI 2-S | 64.63 | 72.76 | VI 2-S | 66.53 | 71.72 |
| VI 6-S | 72.28 | 88.55 | VI 45"-S | 59.08 | 60.28 |
| VI 2-S | 69.73 | 59.63 | VI 2-S | 66.68 | 58.22 |
| TO | 82.61 | 86.01 | TO | 78.12 | 88.25 |
| VI 2-S | 77.81 | 70.34 | VI 2-S | 89.61 | 88.45 |
| VI 1-S | 63.72 | 57.06 | VI 1-S | 64.10 | 66.10 |
| VI 2-S | 58.15 | 55.04 | VI 2-S | 75.35 | 82.19 |
| VI 4-S | 88.18 | 72.93 | VI 4-S | 88.28 | 90.48 |
| VI 2-S | 75.40 | 78.09 | VI 2-S | 94.95 | 87.37 |
| VI 45"-S | 39.30 | 26.17 | VI 2 | 63.87 | 80.16 |
| VI 2 | ----- | 49.28 | VI 2-S | 79.27 | ----- |
| VI 45"-S | 33.22 | 38.44 | VI 2 | ----- | 58.73 |
| | | | VI 45"-S | 52.88 | 57.52 |
| | | | VI 45" | 62.41 | ----- |

APPENDIX (continued)

MEANS OF FIRST FIVE DAYS AND LAST FIVE DAYS:
NONSIGNALLED COMPONENT

| P-6 | | | P-7 | | |
|---|---|---|---|---|---|
| | $\bar{X}_1$ | $\bar{X}_2$ | | $\bar{X}_1$ | $\bar{X}_2$ |
| VI 2 | ----- | 50.91 | VI | ----- | 43.01 |
| VI 2-S | 61.05 | 47.44 | VI 2-S | 43.67 | 38.51 |
| VI 2 | 44.94 | 59.37 | VI 2 | 46.56 | 67.68 |
| VI 2-S | 54.13 | 57.37 | VI 2-S | 54.75 | 50.22 |
| VI 6-S | 58.52 | 43.60 | VI 45"-S | 47.99 | 37.24 |
| VI 2-S | 53.58 | 53.73 | VI 2-S | 62.72 | 61.63 |
| VI 45"-S | 41.41 | 43.57 | VI 6-S | 77.96 | 90.14 |
| VI 2-S | 56.10 | 52.19 | VI 2-S | 87.13 | 77.45 |
| TO | 59.24 | 71.23 | TO | 91.56 | 100.60 |
| VI 2-S | 55.30 | 41.97 | VI 2-S | 93.34 | 81.98 |
| VI 4-S | 47.83 | 66.80 | VI 1-S | 80.34 | 85.96 |
| VI 2-S | 55.08 | 60.46 | VI 2-S | 96.76 | 104.13 |
| VI 1-S | 50.99 | 51.67 | VI 4-S | 106.36 | 112.13 |
| VI 2-S | 59.32 | 58.62 | VI 2-S | 103.46 | 102.68 |
| VI 6-S | 60.30 | 60.69 | VI 1-S | 98.72 | 89.59 |
| VI 2-S | 53.94 | ----- | VI 2-S | 91.16 | ----- |
| VI 2 | ----- | 44.16 | VI 2 | ----- | 93.13 |
| VI 45"-S | 45.08 | 44.70 | VI 45"-S | 80.05 | 81.65 |
| VI 45" | 44.10 | ----- | VI 45" | 66.92 | ----- |